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V.—*On the Drainage of Haarlem Lake.* By SAMUEL DOWNING, ESQ., LL. D. Professor of Civil Engineering in the University of Dublin.

Read February 12, 1855.

THE Lake of Haarlem, situated in the northern part of North Holland, is (or, we should now more correctly say, was) a large fresh-water lake lying between Leyden and Amsterdam, and reaching within two miles of the city of Haarlem, from which it derives its name. Its general outline is, as appears from the Map, Fig. 1, Plate X., of an irregular oblong figure; its greatest length, from north to south, being about 14½ miles, and greatest width, from west to east, about 8 miles; the total area being 44,500 statute acres; and the average depth 13 feet; the surface of the water was nearly on the level of the sea. Fig. 1 is a map of the Lake, after the boundary dyke and canal had been finished, but before it was finally closed in at Halfwege, Sparndam, and Katwyck canal. The dotted lines, within the area of the Lake, show its boundaries at the several dates figured upon them. On the eastern side are shown the minor lakes with which it was feared Lake Haarlem would soon have been connected had not it been laid dry.

Fig. 2 shows the several water-courses excavated in the bed of the Lake, leading the surface water from rain or infiltration to the three pumping-engines by which it is elevated into the surrounding canal, from which it is finally discharged into the sea. The bed of the Lake is now laid dry; the land thus obtained has been sold, and the greater part will this summer produce some kind of crop, a clear addition of about 70 square miles having been thus made to the agricultural resources of that country.

It is my present object to give some account of the more interesting operations by which this result has been so successfully obtained. It will facilitate this end if we first consider some of the physical peculiarities of Holland, its formation, the rain-fall, evaporation, &c. It would be a great mistake to suppose that this country is all a mere Delta of the Rhine; the comparison of the coast-line of Holland with those of the Deltas of the Ganges, the Mississippi, and the Nile, would, from the great difference in the contour of the sea level, which they all, as compared with Holland, express, lead one to suspect some corresponding difference in the character of their respective formations. A more intimate knowledge of this country will, I think, confirm the impression thus raised, at least as to all the more northern districts, in which we find, prevailing over a large area, a dark peat, sometimes more than 30 feet deep, resting on sand or clay, the level of its *surface* being seldom above mean tide level, and very frequently much below it.

Nor is the river Rhine one of those that carries down to the coast any very large proportion of sediment, as may be concluded from a comparison of it with these other rivers, in reference to the weight of earthy matter in suspension:—Oxus, 250 lbs.; Yellow Sea, 50 lbs.; Ganges, 22 lbs.; Wear, in floods, 16 lbs.; Mississippi, 6 lbs.; Rhine, $\frac{2}{3}$ lb. in 1000 gallons.

In fact, so far from being a Delta, ever increasing by successive deposits, we may regard this territory as the fragmentary relic of some larger region, which has been devastated by the ocean, and is now only preserved in its present outline by the unceasing care and industry of man. Many of these inroads of the ocean are well-remembered historical facts; the present inland arm of the sea, called the Zuyder Zee, was the result of a terrible storm in 1287, in which 80,000 persons perished, and cattle innumerable; and, ten years before, the tract of land which now forms the Dollart was swallowed up; and a long list of similar disasters might be enumerated.

Along the sea-board of the German Ocean the country is protected naturally by a high ridge of sand-hills, which stretch along the coast from near Dunkirk to the Helder. On every other part the waters are kept back by immense sea-dykes; and not only on the sea-coast, but also on each bank of the intersecting rivers, are these necessary. The annual cost of the maintenance of the dykes, and the other necessary works, is about £600,000. From this view of the relative position and levels of the land and water, we hardly require the authority of Elie de Beaumont to give force to the supposition of some great subsidence of the land having taken place, its original conditions being such as to facilitate the formation of a vast extent of peat of considerable depth.

The range of the rise and fall of tides (a most important physical feature in the artificial drainage of this country, as we shall perceive) is about six feet along the coast of the German Ocean. Within the Zuyder Zee the rise at Amsterdam and in the River Y is barely 2 feet. The prevailing wind is (and we shall find hereafter that this is one most important agent in freeing this part of Holland of its injurious excess of water) the south-west. Nor must those peculiar circumstances of the great intersecting rivers of the Continent, which bear upon the safety of Holland, be omitted here; these rivers are always frozen over in winter, and frequently the rain-fall and melting snows of the higher districts of the Continent are brought down in great volume before the ice in the lower part has disappeared. If, coincident with this, a westerly wind has forced back a spring tide into the mouths of the rivers, and keeping up the shattered ice as a great dam, thus causing the land flood (already, it may be, up to the very edge of the dykes) to rise yet higher, and burst with fury over the now defenceless fields. It is from some *conjunction* of unfavourable circumstances, such as those mentioned, that Holland has generally suffered. In 1799 the very existence of the country was threatened from this source, the Rhine rising 7 feet in one hour at Nymegen. The improvements in the bed of the river Rhine, even as high up as Bingen, have been a cause of increased anxiety and expense to Holland, by bringing down the waters of land floods and melting snows of the Alps more suddenly upon their dykes. An average of thirteen centuries would show that they have had some severe disaster, either from sea or river, once every seven years.

The annual amount of rain-fall and evaporation is another natural feature of even greater importance to this than perhaps any other country. The mean fall, deduced from observations of 100 years, is 25·1 in.; the mean evaporation 22·6 in., giving a difference of only 2·5 in. of excess of rain-fall.

From the earliest times this country has been divided into different districts, of greater or less extent according to circumstances, which districts are protected and bounded by great dykes that oppose the entrance of the surrounding waters. These districts have been placed under regular administrations, whose rights and privileges have been guaranteed by the head of the State, and have always been respected through every change and revolution, and notwithstanding all the other divisions and subdivisions of the country, whether fiscal or judicial. Their principal duty always has been to make and maintain the means of defence against an invasion of the surrounding waters, whether from the sea, the rivers, or conterminous administrations. All these waters, of whatever kind, which threaten the boundary dyke, are denominated the *external waters.* But within this bounding dyke are also found extensive areas of water, arising either from rain or snow, or infiltration from surrounding waters, or from natural springs; which last are, however, but rare. These interior waters, although in part carried off by evaporation, would, nevertheless, rise too high within the dyke (and become as injurious as the external waters) if they could not flow off whenever circumstances may lower the surface of the latter. Every boundary dyke has, therefore, one or more self-acting sluices, which permit the discharge outwards, but close whenever the external waters are higher than the internal. Other communications are also opened through the boundary dyke, for the purposes of navigation and irrigation.

The Administration for Hydraulic Works of the Rynland, as containing the Lake of Haarlem, of which we are treating, will best illustrate the nature of this territorial division. Its artificial boundary is shown by a dotted line upon the Map, Fig. 1, Plate X. It discharges its waters at three points:—1. On the north, at Sparndam and Halfwege (that is half way between Haarlem and Amsterdam), into the River Y, and so into the Zuyder Zee. 2. On the south into the German Ocean, at Katwyck sluices. 3. Into the River Yssel at Gouda; in all, eleven sluices, having a total breadth of about 280 feet.

Within the bounds of every Hydraulic Administration are found three great divisions of the surface, technically named the *natural lands*, the *basin*, and the *polders.* The NATURAL LANDS are those which, as being above the surface of the internal waters, permit the rain to flow naturally off their surface. The BASIN consists of the surface of all the internal waters whatever, marshes, lakes, canals, and drains,—all having one surface level, and in free communication; the level of the surface of the basin is in general a little lower than that which the waters would have in summer, if the boundary dyke did not exist. The POLDERS are the lands lying below the level of the water of the basin, and must therefore be kept dry by artificial means, each separate polder being surrounded by its own dyke to keep out the waters of the basin; over which dyke the waters of the polder must be raised mechanically. The depth of the land in the polders, below this level, varies from a few inches to 20 feet.

In the Rynland Hydraulic Administration the relative areas of these three descriptions of surface are:—

Natural Lands (two-thirds of which are Dunes or Sand-hills),	76,000 acres.
Basin,	56,000 ,,
Polder Lands,	173,000 ,,
	305,000 acres.

From which we have this surprising result, that but one-fourth of the total area is land situated *above* the level of the water; let the boundary dykes fail, or the mechanical raising of the waters cease, and the vast area of 173,000 acres reverts to its original condition, becoming again covered with water.

It will be understood now, from what has been said, that when the exterior are lower than the interior waters, the basin acts as a channel to conduct the waters flowing off the natural lands, and raised mechanically from the polders to the sluices in the boundary dyke, and so to the sea; but if, on the contrary, the exterior waters are at any time higher than the interior, the basin acts as a *reservoir* to contain these waters derived from the natural lands and polders, until a favourable time for discharging them through the sluices arrives. Hence, if for any lengthened period the external waters remain at a high level, closing the self-acting sluices, and stopping the discharge of the internal waters, the proportion of the *area* of the basin, relatively to that of the rest of the administration, becomes of the highest importance, for at every polder there is a scale fixed, like the scale of feet at a dock entrance; the zero of these scales, which is common to the whole country, is the top of a certain pile at Amsterdam, and is briefly called the A. P. (Amsterdam pile), or O. A. (zero of Amsterdam). It is about the mean level of the tides in the Zuyder Zee, and also the surface of the natural lands in the greater part of the two provinces of Holland. It is most suitably, then, the point of reference in all hydraulic works and observations in this country. Upon the scale I have described, there is a point marked, called the *point d'arrêt*, or point of stopping, which is the same height for all the polders in each administration, but not the same for every different administration; and when the interior waters of the basin have reached this point, then all the windmills and steam-engines raising water from the polders must cease working, although the consequence of this, if the stoppage continue long, must be, that they become, to their great injury, covered with water; this, however, is the lesser of two evils,—for the point of stoppage has been fixed with a reference to the height of the natural lands, and the lower and weaker of the banks surrounding the polders.

The consequence, then, of permitting the surface of the basin to rise above this point by any further continuing the mechanical lifting of the water of the polders, would be to flood the natural lands, and cause the water to flow back into the polders over the top of their boundary dykes, not only flooding the lands below, but endangering the bank being cut through by the rush of water over the top.

Upon the *area* of the basin, therefore, multiplied into the vertical depth from the point of stoppage to the level that the surface had at the time the self-acting sluices closed against the exterior waters, depends the volume of rain that may fall upon the total area of the Hydraulic Administration, without entailing the great injury of a cessation to the mechanical drainage of the polders.

We may illustrate this by the Rynland. Let us suppose the level of the surface of the water in the basin to be 1 foot 2 inches below the point of stoppage, and the self-acting sluices closed, the external waters being from any cause raised above that point. Let 3 inches' depth of rain be supposed to fall in the week over the whole 305,000 acres; this will raise the basin of 56,000 acres, 3 inches, by that which falls directly upon it, no evaporation being supposed to take place, and the rain upon the polders, being also thrown off as it falls, being raised by the windmills and steam-engine, 3 inches upon 176,000 acres, will be equal to 9·4 inches on 56,000, and 3 inches falling on the natural lands; and, flowing down on the basin, will raise it 4 inches. Thus, the total rise of the basin would be 1 foot 4·4 inches, or 2 inches above the point of stopping; the engines raising the water from the polders would, therefore, have to cease working before they had discharged that amount of rain-fall; nor can it be recommenced until the exterior waters have fallen below the *point d'arrêt.* We see now what a change in the Rynland has been made by laying dry the Lake of Haarlem: 44,500 acres have been deducted from the Basin, and added to the Polders. Instead, therefore, of 56,000 and 173,000 acres respectively, we have 11,500 and 217,500 acres for the areas of basin and polders:—

	Before Draining Lake.	After Draining Lake.
Natural Lands, ...	76,000 acres.	76,000 acres.
Basin, ...	56,000 „	11,500 „
Polder Lands, ...	173,000 „	217,500 „
	305,000 acres.	305,000 acres.

Consequently, instead of the basin being able to bear nearly 3 inches of rain-fall without stopping the discharge of water from the polders, as in the example just given, it would not bear three-quarters of an inch without producing the same evil effect. The authorities of the Rynland were, therefore, justified in demanding from the Commissioners of the Drainage of Lake Haarlem guarantees that it should not, when completed, entail any injury upon the rest of the district under their charge.

In another interesting point of view it was necessary to guard against any injury to this Administration by the successful drainage of the Lake.

It has been observed in navigable canals, that in very long and straight reaches, the surface, which in calm weather is truly level, becomes, when the wind blows with force and for some time in the direction of the length of the canal, inclined, and sometimes so much so as to impede the navigation. The Dutch have utilized this fact, so inconvenient to others, for, though it may seem almost incredible, the surface of Lake Haarlem was observed, when the wind, generally south-west, blew strongly for some time in the direction of its length, to have a difference of level of upwards of 3 feet, the northern extremity being that much higher than the southern: it is easy to perceive how powerfully this aids the discharge through those sluices towards which the wind impels the waters. A south-west wind not only raises the Lake against the northern sluices, but lowers the surface of the Zuyder Zee, depressing its waters outside the same points by the operation of the same cause, and thus doubling the beneficial effect on the discharge of the waters of the basin of the Rynland.

It is true, the sea is raised at Katwyck sluices, but here the rise and fall of the tide is so much greater than in the Zuyder Zee that, unless in great storms, these always have some discharge at every low water. The action of the tides is irregular, and almost disappears on the northern part when the winds are high. If, then, Lake Haarlem be laid dry, it is evident this mode of lowering the basin of the Rynland must cease, and that too, at a time when, from the diminution of the area of the basin, which I have mentioned, the position of the district had become more critical. We may now more readily understand how it was that so many different projects were put forward, and such a length of time elapsed, before this work, which seemed in different ways to compromise the safety of the rest of the Rynland, was finally undertaken. It was under consideration for 200 years; fifteen different projects having been mooted in that time. It was, however, in a manner forced upon the Government by the dangers arising from so vast a body of internal water, surrounded by shores of such yielding material as peat.

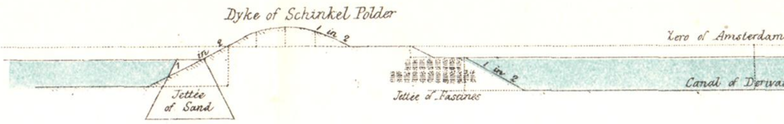
The fresh-water lakes of Holland, although seemingly so sluggish and inert, yet contain within themselves a principle of increase: most frequently formed by the cutting away of turf for the purpose of fuel, and separated from each other by narrow intervening banks; a storm arising, drives the waters with fury against the too yielding bank—this soon disappears, and the area of the united waters falls with increased power upon the next opposing mass, which in its turn gives way, and after some years a large and dangerous expanse of waters is seen, which can only be restrained from further injury by expensive works. It was thus that Lake Haarlem, which in 1531 consisted of four small contiguous lakes, was gradually formed; the boundaries of these are given in the map, Fig. 1, Plate X., with the several dates upon the lines showing the then boundaries of the waters. It was only by lofty and expensive dykes along the eastern shore, and an expenditure of about £5000 a year in repairs, that it was prevented joining the Lakes of Aalsmeer, and finally attacking Amsterdam itself.

On the 9th of November, 1836, a violent storm from the south-west forced the waters over the dykes, and flooded all the lands up to the gates of Amsterdam, causing great destruction of property; and, on the following Christmas Day, an equally violent gale from the opposite quarter drove the waters over

MAP
OF THE
HYDRAULIC ADMINISTRATION,
OF THE
RHINLAND,
Including the Works for the Drainage of
LAKE HARLEM.

Scale._ 200.000 to One.

FIG.



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Scale 480 to

FIG. 2.

LAKE AFTER DRAINAGE.

Scale._ 180.000. to One.

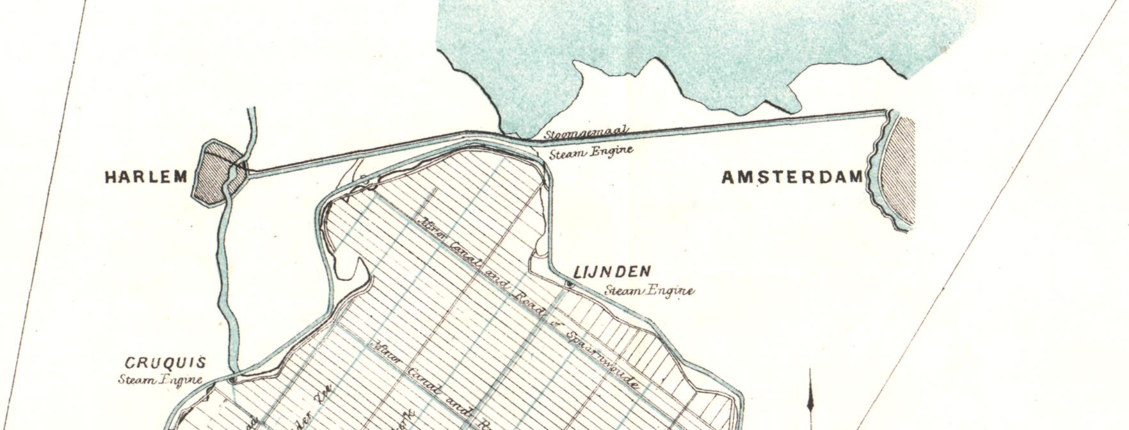

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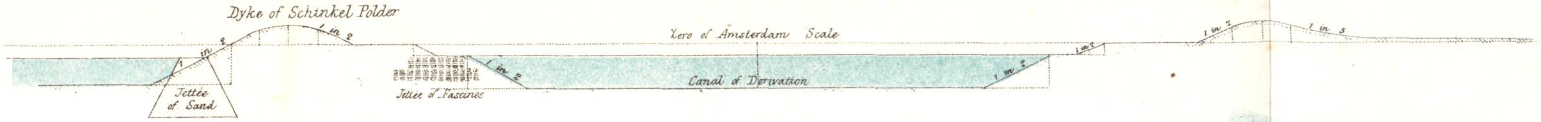
FIG. 3.



SECTION THROUGH SCHINKEL POLDER.

Scale 480 to One.

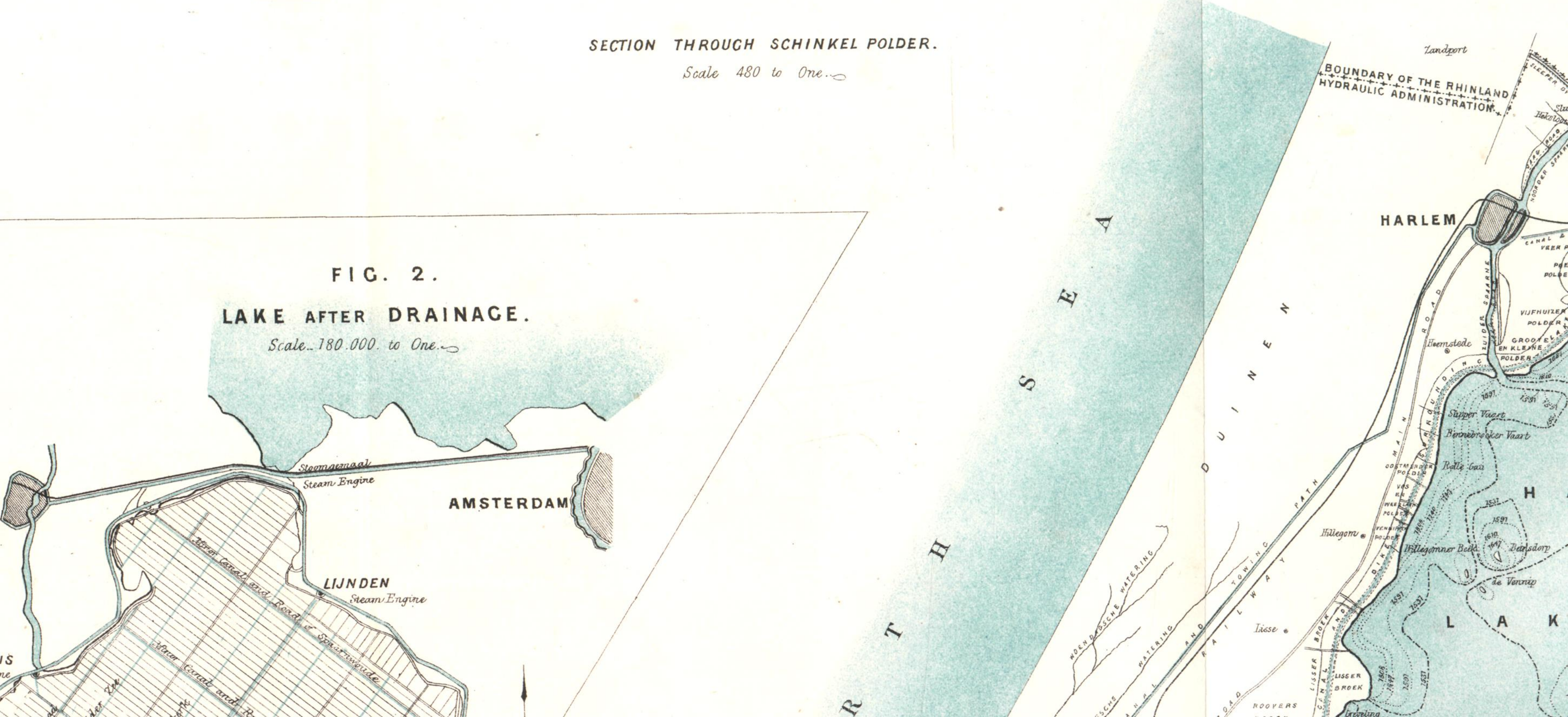


FIG. 2.

LAKE AFTER DRAINAGE.

Scale 180.000 to One.

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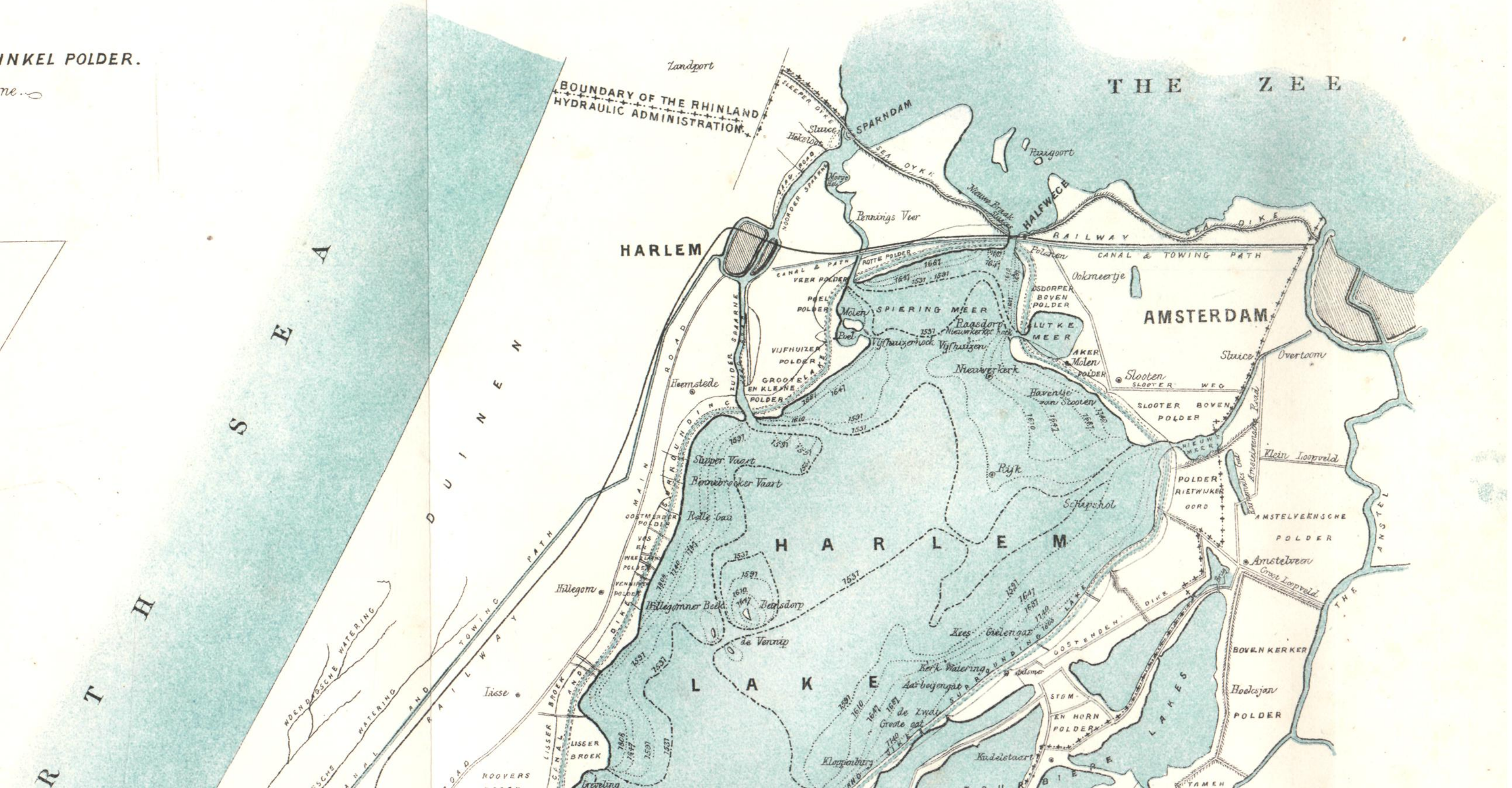
FIG. I.



HYDRAULIC ADMINISTRATION,
OF THE
RHINLAND,
Including the Works for the Drainage of
LAKE HARLEM.

Scale. _ 200.000 to One.

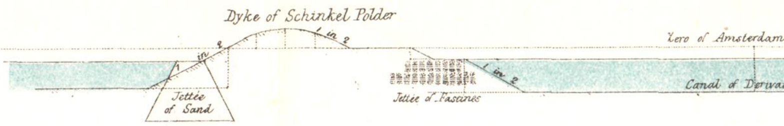


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FIG. 2.
LAKE AFTER DRAINAGE.
Scale. 180.000. to One.

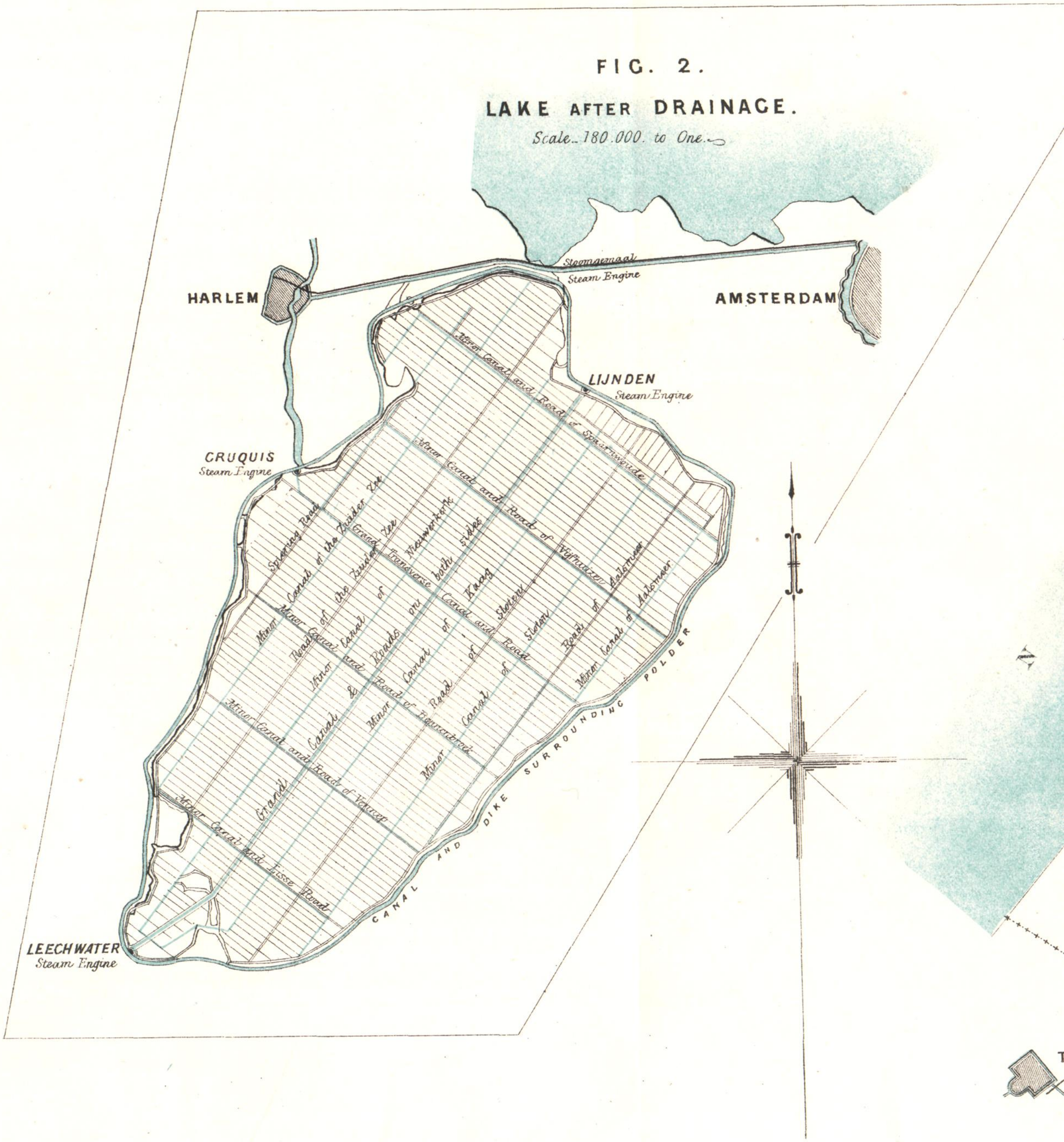
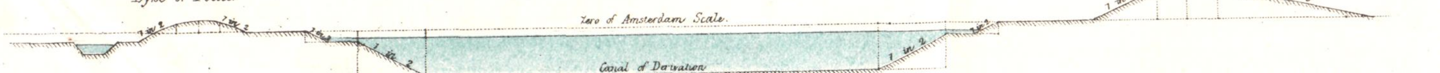
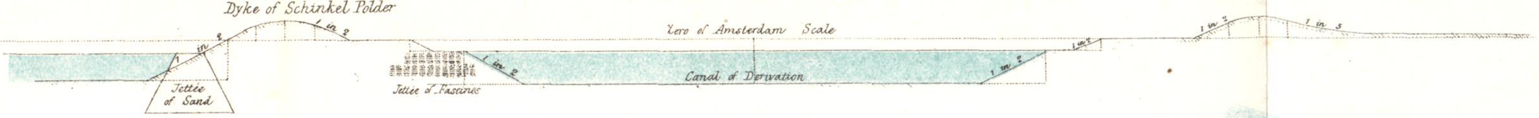


FIG. 4.
SECTION FROM HALFWEGE TO SCHINKEL POLDER.





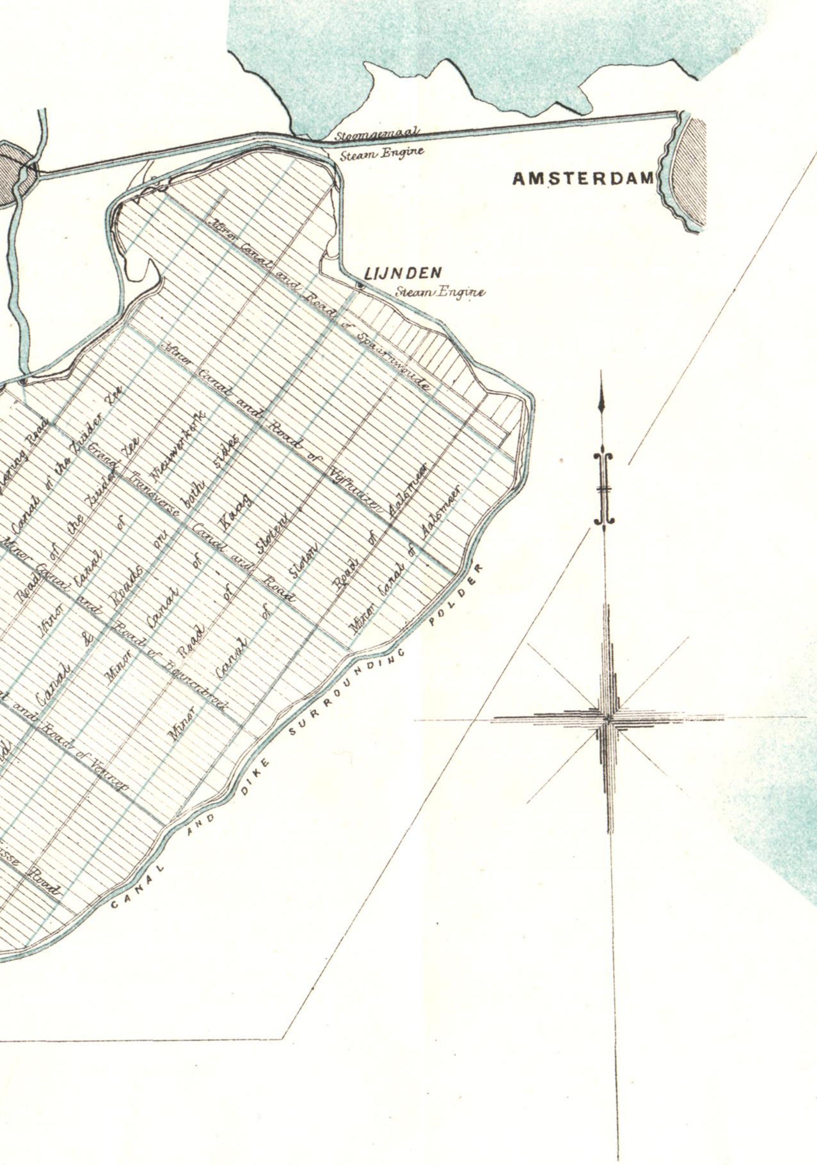
SECTION THROUGH SCHINKEL POLDER.

Scale 480 to One.

FIG. 2.

LAKE AFTER DRAINAGE.

Scale 180.000. to One.



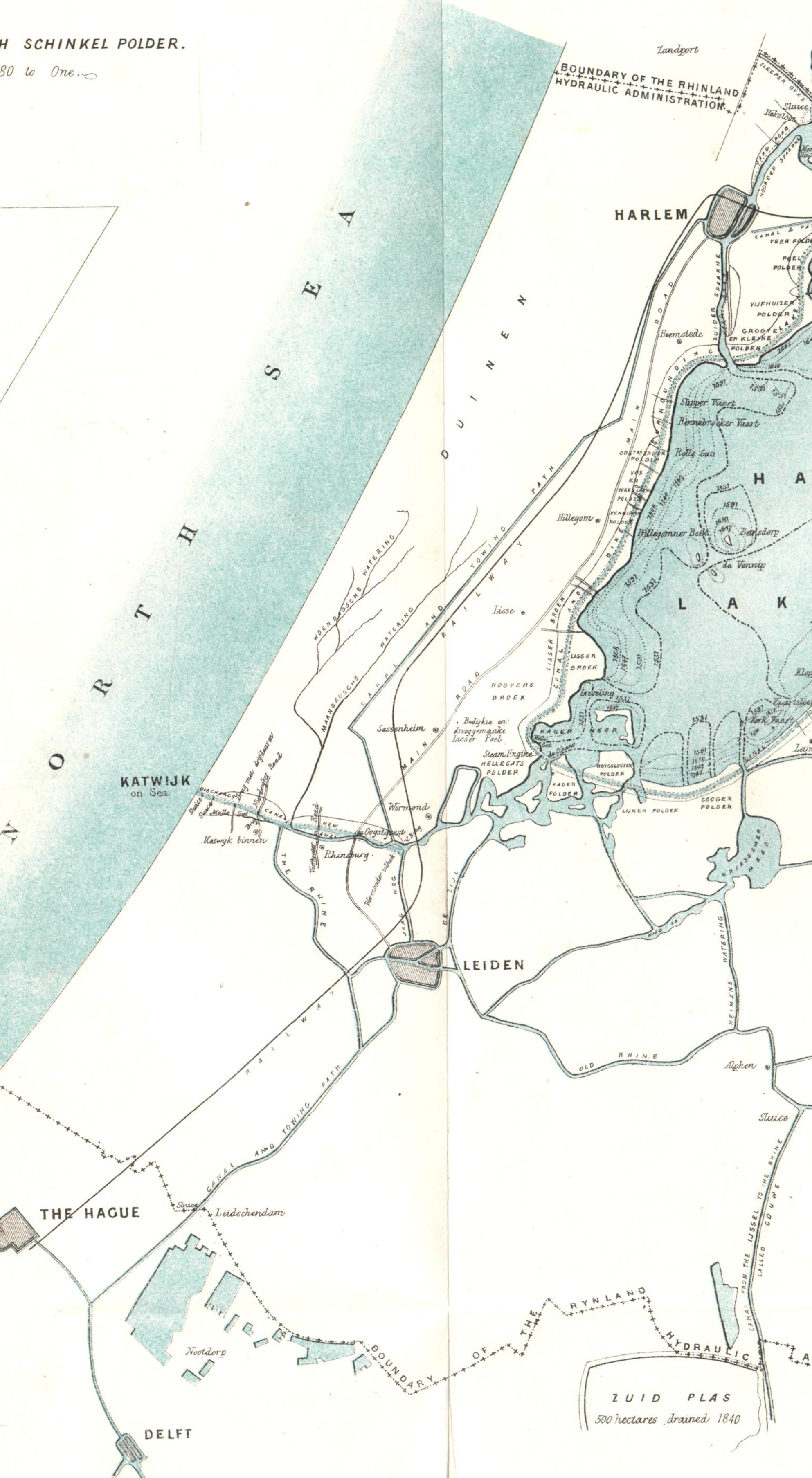
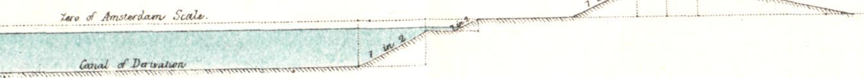


FIG. 4.

FROM HALFWEGE TO SCHINKEL POLDER.



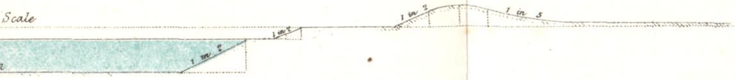
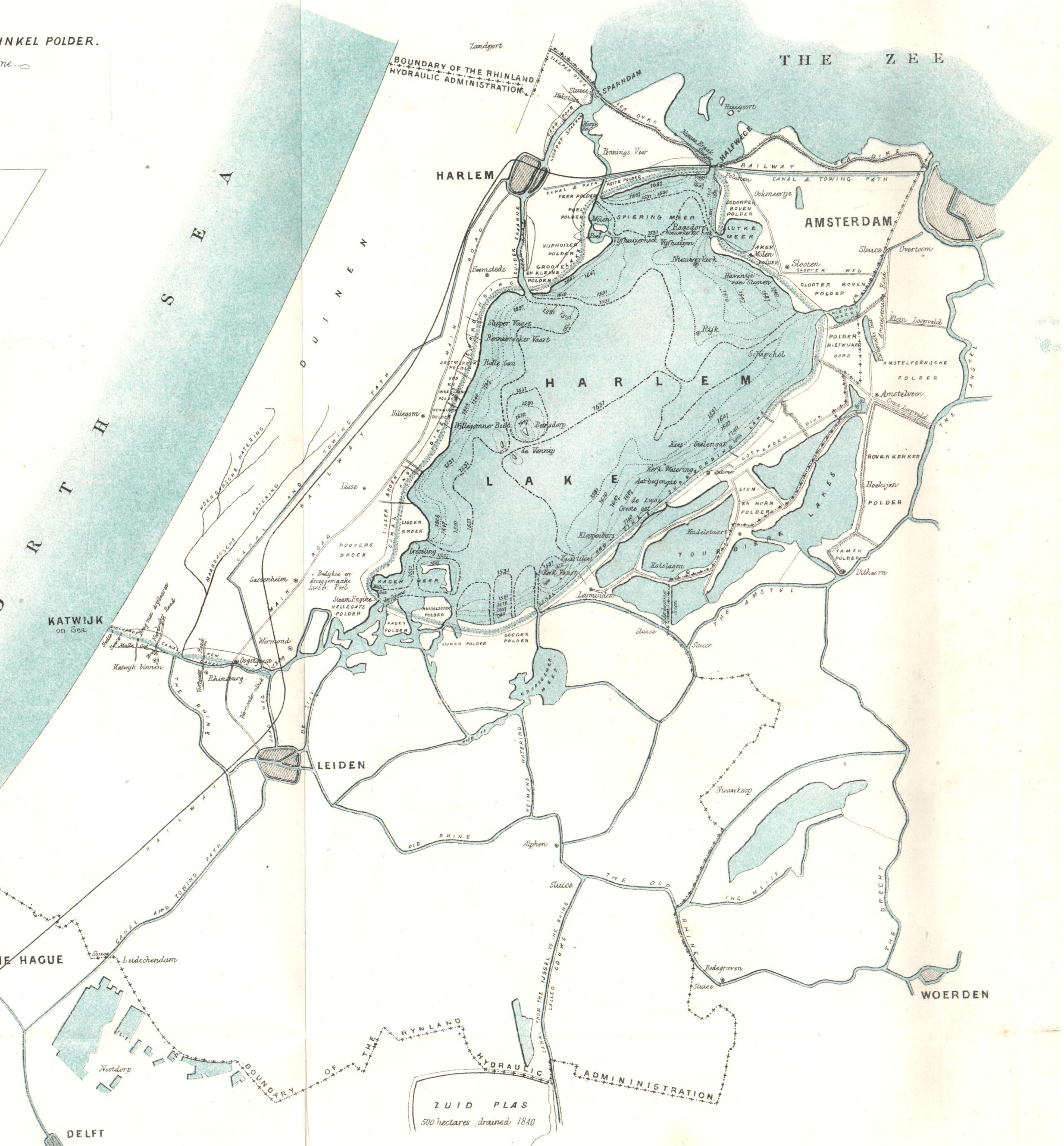


FIG. I.

NKEL POLDER.



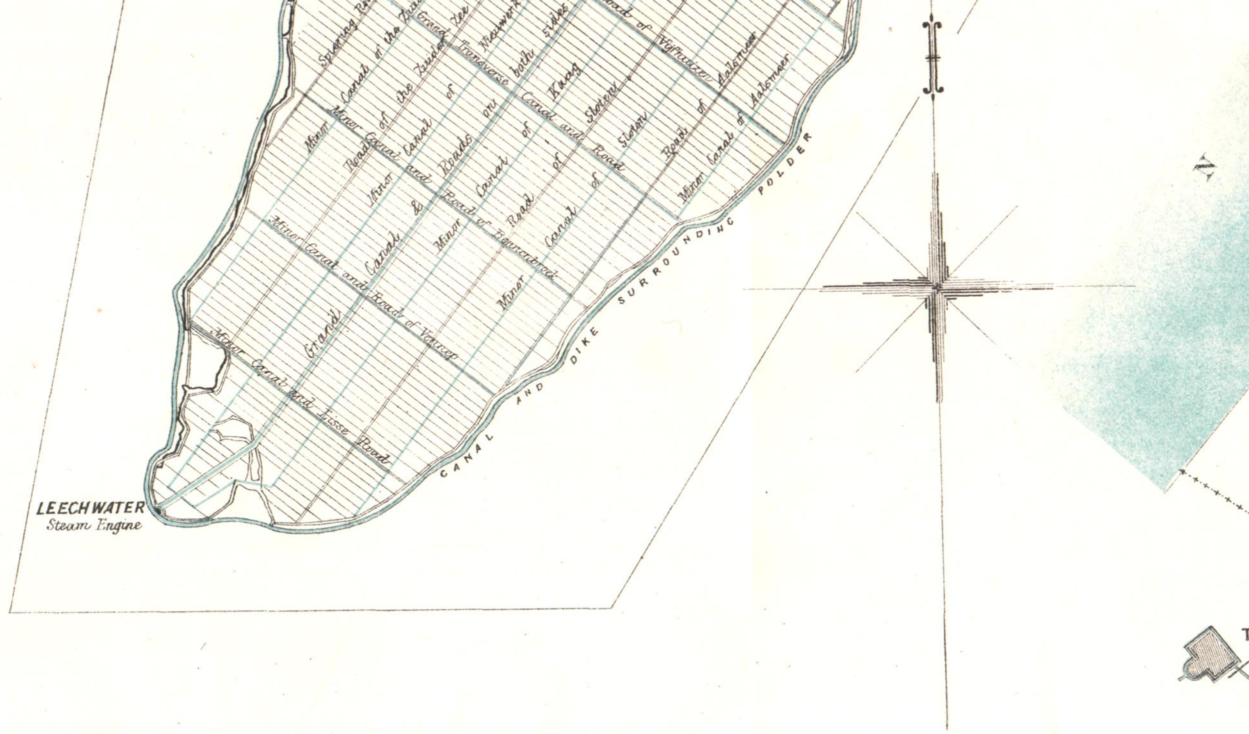
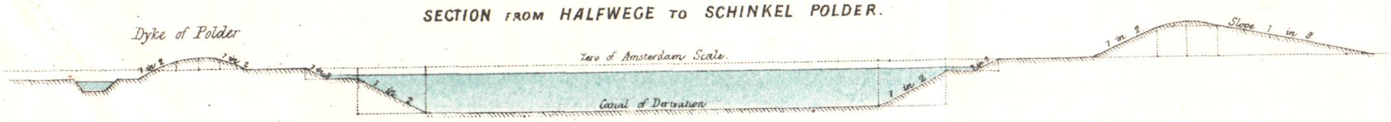


FIG. 4.

SECTION FROM HALFWEGE TO SCHINKEL POLDER.



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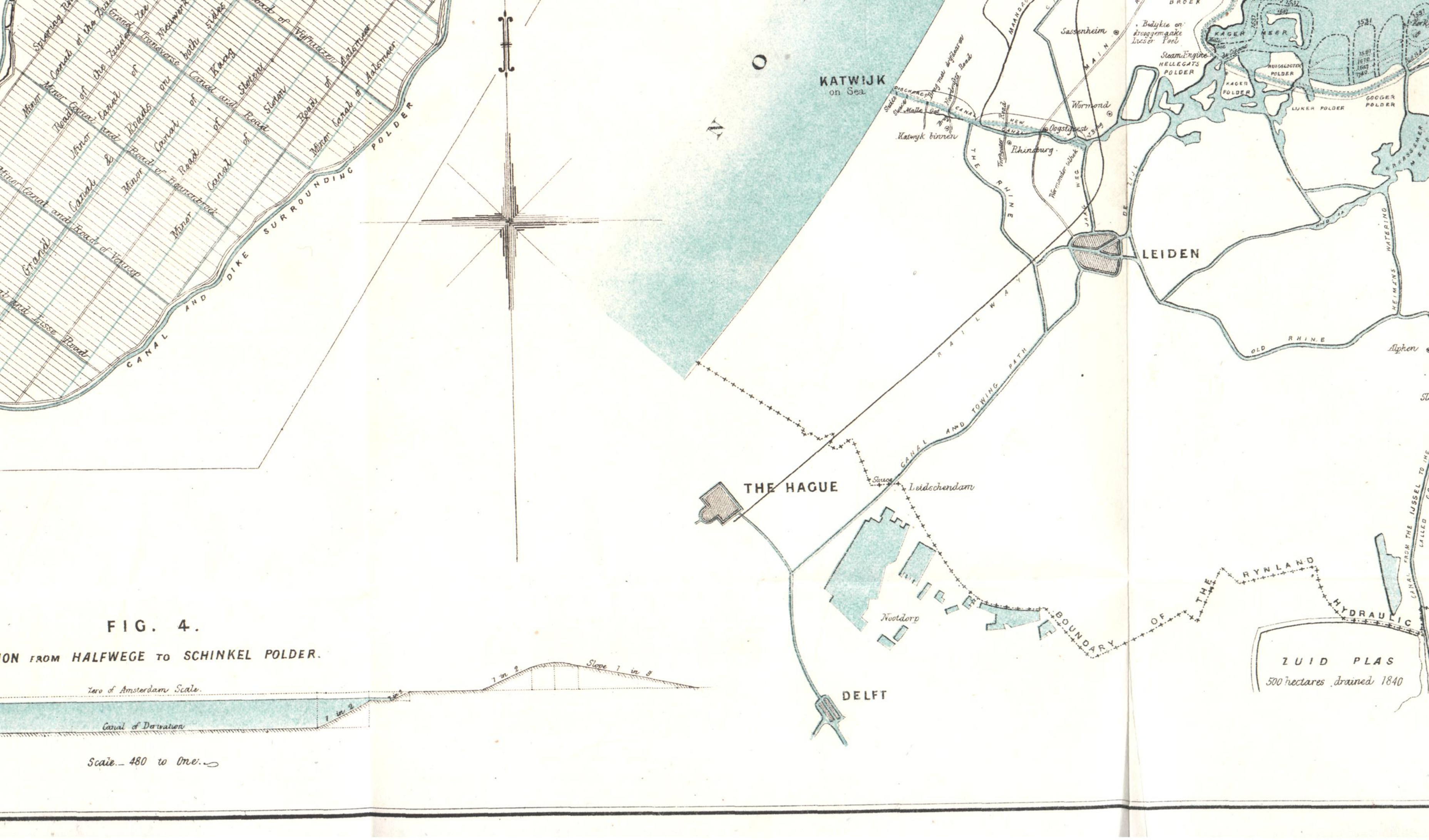
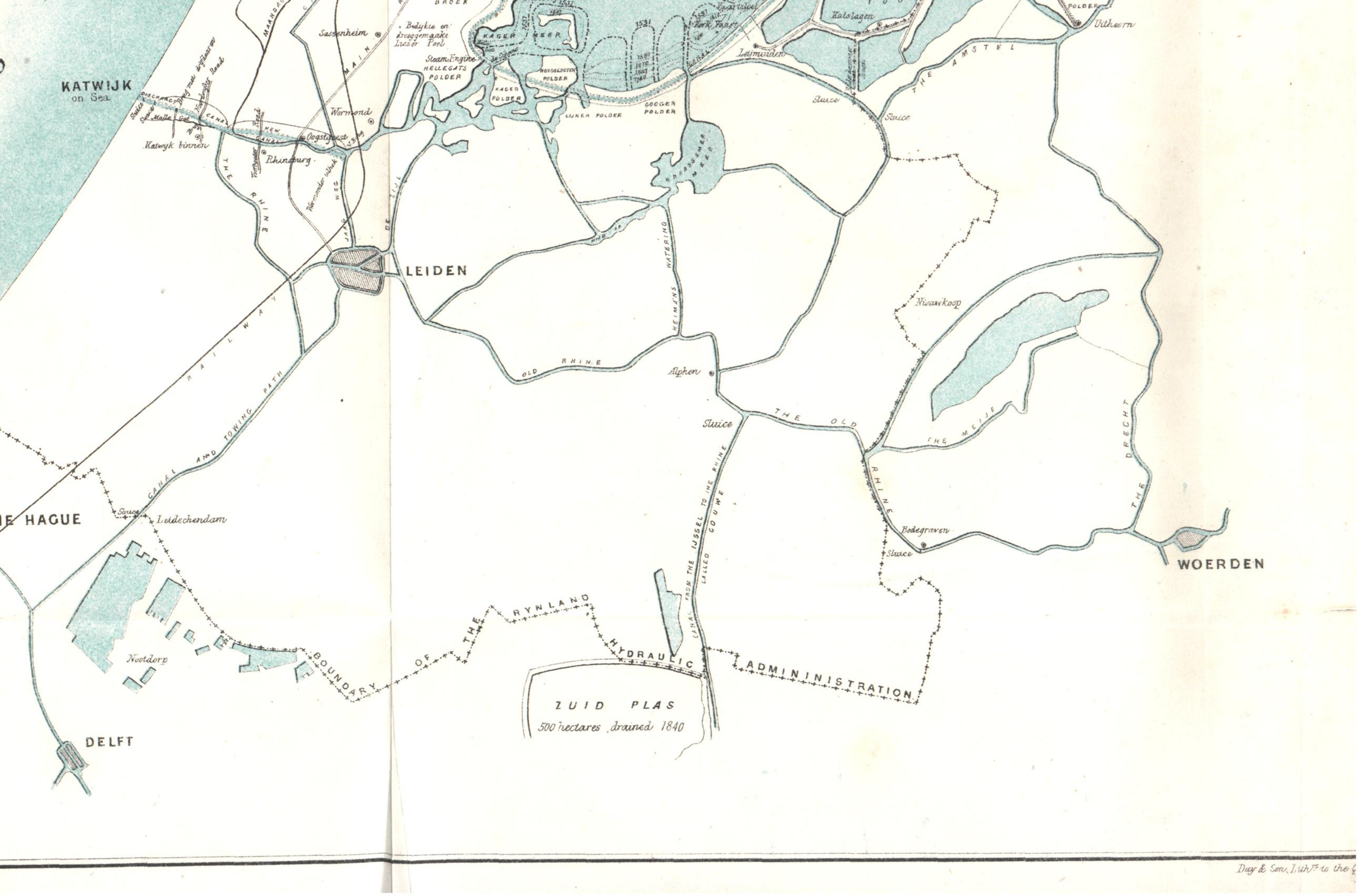


FIG. 4.

ON FROM HALFWEGE TO SCHINKEL POLDER.

Scale 480 to One.



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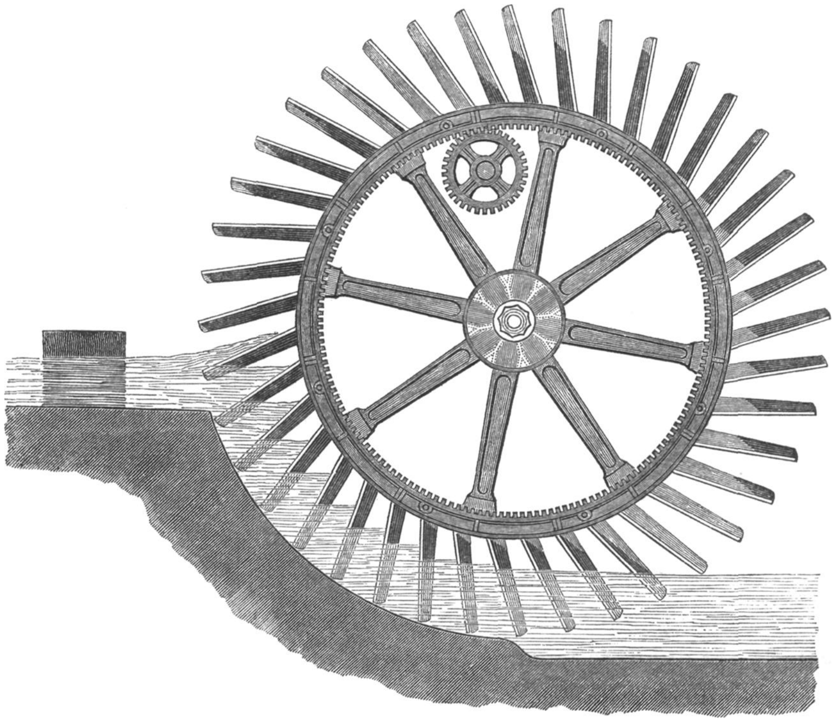
every barrier up to the very streets of Leyden, causing loss of life, of cattle, and property; nor were the damages repaired for more than a twelvemonth.

The Government now at last resolved to complete the work so long projected. A Commission was formed to report upon the plan to be followed, and a credit granted by the States-General. The first of the engineering works of the drainage were more directly connected with the security of the basin of the Rynland than with the Lake itself, and consisted in widening and straightening the canal leading to the Katwyck sluice. This canal had been originally formed (in 1806) about 90 feet wide; it was now made to be 170, which involved the lengthening of the bridges, and increasing the number of the inner line of the sea sluices at Katwyck; the outer line has not been altered. On the north side, the River Sparn was deepened and improved, and an engine of 200 horse-power erected to discharge water from the basin into the Y, when the flow of it outwards was otherwise impossible. Additional sluices were also constructed at Halfwege, and quite recently, a second engine of 100 horse-power has been put up here, like that at Sparndam, which was found insufficient by itself to keep down the surface of the basin.

The first *direct* operation of the laying dry the bed of the Lake was (as is always necessary when gaining new polder land) to completely surround it with a large and water-tight dyke, to separate it from all other waters of the basin; in *this* lake it was, moreover, required to provide for that inland navigation which had been hitherto maintained over its waters, and thence up the several channels leading to all parts of the basin of the Rynland. A navigable canal, called the Ringvart, was, therefore, directed completely round the Lake, its inner bank being the surrounding dyke, and the outer formed of the stuff cast out of the canal bed, which had a width of 140 feet, and depth suited to vessels drawing 8 feet of water, such as were used in the former navigation of the Lake. Transverse sections of the Ringvart at two different points are shown in Figs. 3 and 4, Plate X. The length of this canal was about 36 miles.

As to the *kind* of *power* to be used in extracting the water, namely, whether wind or steam, the Commissioners having rejected the idea of using the ancient windmills of the country, or wind with steam as an auxiliary working the scoop-wheel shown in the annexed woodcut, adopted the designs of Messrs Gibbs and Deane, which had been obtained by three of their body, deputed to visit England to examine into the working of the far-famed Cornish pumping-engines. As to the *amount* of *power* to be applied to laying dry the Lake, an interesting practical problem presents itself. We must, in the first instance, set up a power to lay dry the polder exactly equal to that required ever after to *maintain* it in that state. If we apply to the exhausting of the water a greater power than that required to keep it dry afterwards, we shall be burthened with the interest upon a too great first cost, and subsequent maintenance, having thus purchased too dearly the earlier laying dry of the polder by an expenditure not commensurate with the gain in time. At first sight it would appear impossible to fulfil the conditions of this problem, and so indeed it would be, if the power to be employed in permanently *keeping dry* the land on the bed of the Lake were required to act continuously, as it must do, in the first instance, in *laying* it *dry*. The power required in the engines must then be obviously equal to the maximum power required to meet the rain-

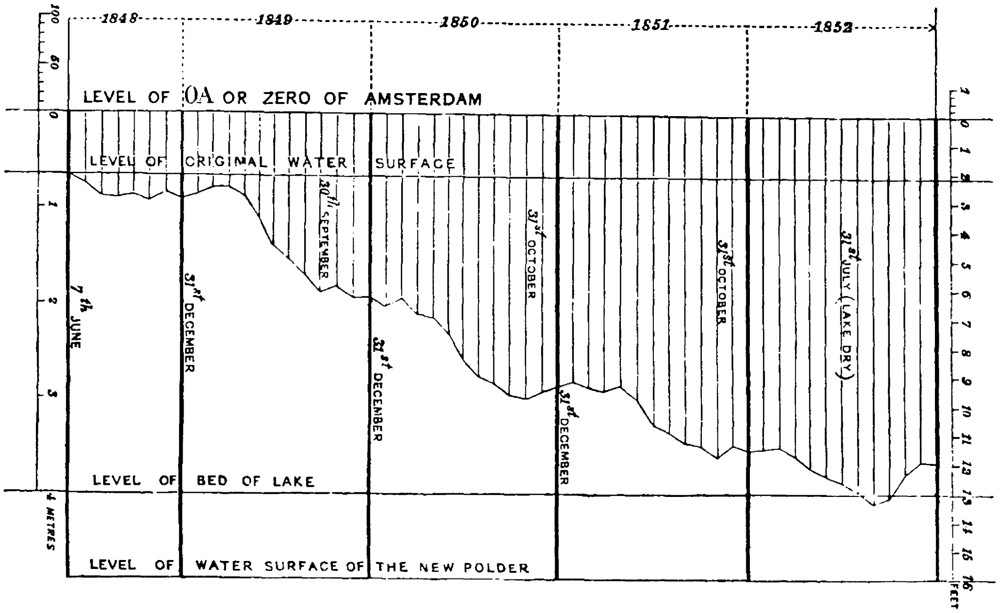


fall in some definite period, as, suppose, one month, together with any infiltration from the external basin.

Observations on the rain-fall of Holland, extending over a period of ninety-eight years, had shown that the greatest depth of rain in any one month was 6·524 inches more than the evaporation for the same period. If we allow 1·47 inches for infiltration, we have a total depth of 8 inches to be thrown off the land in one month, and this has to be raised from the level of the future drains in the polder to that of the water in the Ringvart, a height of about 16 feet. A simple calculation gives 1087 horse-power as necessary to effect this in twenty-five working days per month. It was, therefore, resolved to put up three engines, of 350 horse-power each, and these were located in the positions shown on the map. From the *power* thus required to keep dry the future polder, we may, proceeding in a retrograde order, readily deduce the *time* in which the first operation of laying dry the lake may be effected by that force which we have shown to be necessary to its permanent maintenance, namely, 1087 horse-power. The Lake at 13 feet of depth contained about 800,000,000 tons of water, which had to be raised an average of about 6½ feet of vertical height. With no delay from accidents, or frost, or from the point of stopping being reached, this might be effected in about fourteen months. From a variety of unforeseen causes it required thirty-nine months; and the weight of water actually raised was, as indicated by the counters attached to the engines, upwards of 1,100,000,000 tons. The annexed woodcut, p. 460, shows the rate of progress in each successive month, and by joining the lowest points in each successive year we may perceive how, in each winter season, the rain-fall, with the absence of evaporation, gained upon the power of the engines; the general average lowering of the surface was at the rate of about 4 inches per month; every inch in depth upon the surface weighing upwards of 4,000,000 tons, we may thus form an opinion how prejudicial and expensive such risings must have been, more especially in the latter months, when it had to be raised nearly the full depth of the Lake.

The estimated expenditure at the commencement of operations was £687,500; the result, up to the last published account, which includes the full completion of all the works, was an actual expenditure of £827,200, being an excess of £139,700.

The sale of the land will realize about £400,000, and the land-tax of 7*s.* 4*d.* per acre, being capitalized, represents a nearly equal sum; moreover, the annual cost of the eastern dykes, set down at £5000 a year, now ceases, and in the profit to the State we cannot omit the saving thus effected.



The horizontal line represents time, each equidistant vertical being separated a space taken conventionally as equal to one month. The verticals represent depth from original surface of Lake to surface as lowered at that date, in feet or metres, according as we use either of the comparative scales given, that on the left being metres, and on the right, feet. By joining the feet of these verticals we get an irregular line, from which we may obtain the depth pumped out at any intermediate period.